AVCO EVERETT

RESEARCH LABORATORY

a division of
AVCO CORPORATION

NASA CR70634

QUARTERLY PROGRESS REPORT

Contract NASw-1101
September 1965

prepared for

HEADQUARTERS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY
Washington, D. C.

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AVCO-EVERETT RESEARCH LABORATORY
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Everett, Massachusetts

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I. INTRODUCTION

The most significant accomplishment of the third quarter of the subject contract was the successful demonstration of an elegant means of dispensing with the electron gun; such a gun had previously been thought to be a necessary component of any injection system. The details of this technique, and a discussion of some of its limitations are given in Section II. In theoretical work a stability problem of very direct relevance to the Space Radiation Shield has been solved (Section III) and certain other problems continued.

As in previous quarters, this report will attempt to cover the overall scientific progress in areas relevant to Plasma Radiation Shielding. Some of this work was (as before) supported by an AFOSR Contract* in the area of Plasma Physics Research. It is understood, therefore, that not all the work described herein is attributable to the NASA contract.

II. INDUCTIVE CHARGING EXPERIMENT

Our primary experimental effort has been directed towards increasing the total number of trapped charges in the inductive charging experiment described in the preceding progress report, thereby increasing the total integrated radial potential. Quite successful results have been obtained utilizing the apparatus shown in Fig. 1 wherein the silvered exterior cylinder has been replaced by a slotted solid cylinder in which all of the magnetic flux enters through the slot. In this arrangement, the inward projecting electron gun has been replaced by a single hot tungsten filament which is mounted axially in the slotted section of the exterior cylinder where it is relatively shielded from space charge fields due to the trapped electrons. Utilizing this arrangement, radial potentials in excess of 12, 500 volts have been generated with gap voltages of about 135 volts. Thus we have obtained a voltage amplification factor of over 90. An oscillogram showing this result may be found in Fig. 2.

These electron injection studies are continuing and appear to indicate that for any given geometry the induced radial potential is more nearly proportional to the time rate of change of the magnetic field than to the maximum value of the magnetic field.

The linear inductive charging apparatus will be limited to voltages below 100 KeV by breakdown along the surface of the annular end plates. In order to avoid this limitation, a toroidal machine is being designed and

*AF49(638)-1553

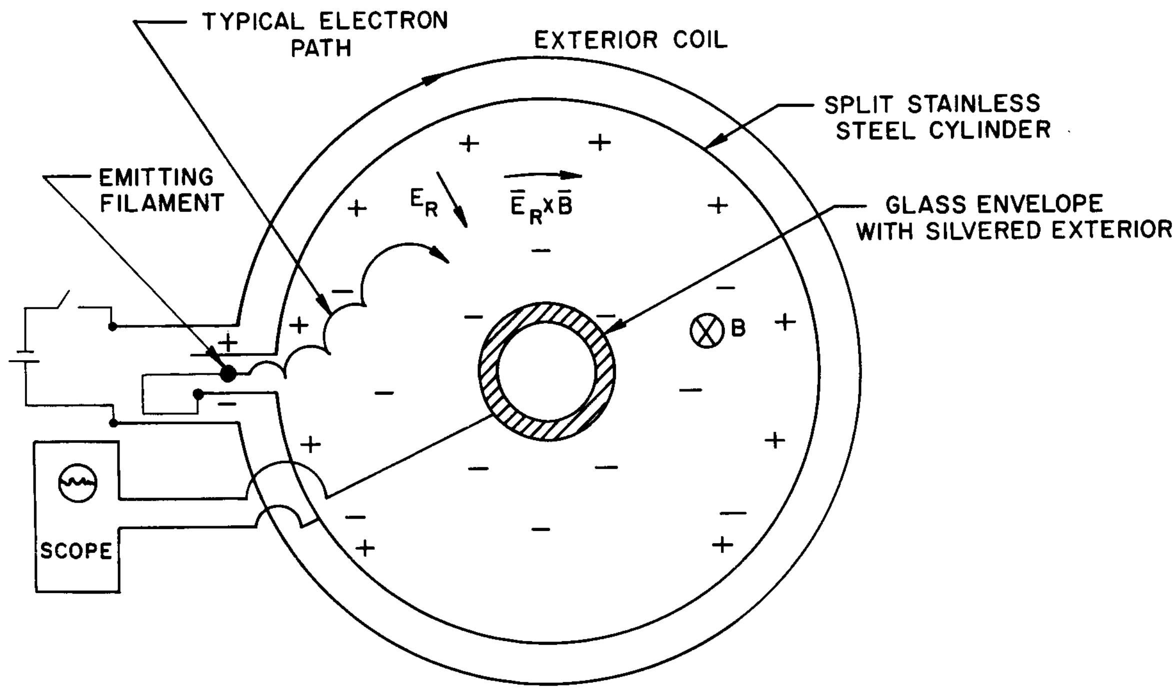

Fig. 1 This figure illustrates the inductive charging apparatus modified to allow injection using the electric field induced by the rising B-field. The magnetic field lines can be thought of as entering through the slot; as they pass the heated filament, they pick up electrons which are then transported into the experimental region.

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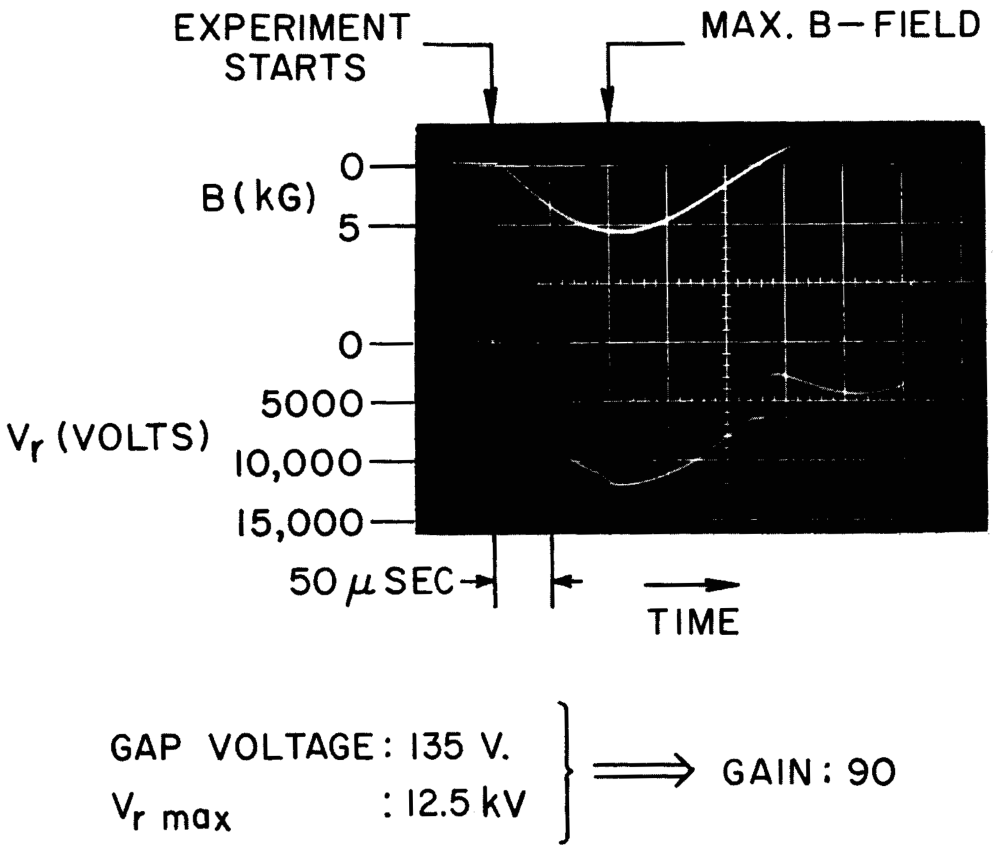

Fig. 2 This oscillogram was obtained with the apparatus illustrated in Fig. 1. The potential induced across the slot by the rising B-field was about 135 volts. The peak radial potential in the system was 12, 500 volts.

and constructed. In addition to avoiding surface breakdown along the walls, this apparatus will also enable us to investigate the effects of grad B drifts in single component plasmas. This phenomenon has necessitated the use of a B field rotational transformer in stellarators; however, we have reason to believe that this will not be necessary with single component plasmas even though all particles drift in the same direction. The toroidal apparatus is being designed in such a way that it will be possible to utilize the new eletron injection technique.

III. THEORETICAL WORK

The principal theoretical achievement of the past quarter was the establishment of conditions under which the Plasma Radiation Shield could be stabilized against the long wavelength diocotron instability. An idealized version of the Plasma Radiation Shield is shown in Fig. 3. For study of the diocotron effect, the torus is straightened into an infinite cylinder as in Fig. 4. This geometry differs from that studied in a previous report in that the magnetic field is azimuthal (instead of axial). As a result, diocotron waves will propagate axially (instead of azimuthally). In the plasma radiation shield, waves of this type could not have wavelengths greater than $2\pi R$. Introduction of this limit yields a definite criterion for stability; this criterion is shown in Fig. 5. Essentially, the beam must come fairly close to the space ship and/or be fairly thick if stability is to be assured. A long paper on this subject has been prepared (Ref. 1), and a short paper with the same title has been submitted for publication to the Physics of Fluids. The abstract of the long paper follows:

"The Diocotron Instability in a Quasi-Toroidal Geometry"

R. H. Levy and J. D. Callen

ABSTRACT

The diocotron (or slipping stream) instability of low density ($\omega_p \ll \omega_c$) electron beams in crossed electric and magnetic fields is considered for a cylindrical geometry with a radial electric field and an azimuthal magnetic field. In the analysis the electrons are assumed to have no thermal energy, collisional effects are neglected, the quasi-static approximation is made, and perturbations of the electric field along the magnetic field are ignored. For a simple density distribution the important normal modes of the electron beam correspond to two discrete eigenvalues. A condition for the stability of these modes is derived. This condition shows that, within the approximations of the analysis, the electron beam can be stabilized against the diocotron modes by proper selection of dimensions. The application of this theory to a proposed toroidally-shaped space radiation shield is discussed. Assuming the long straight cylinder geometry to be a reasonable

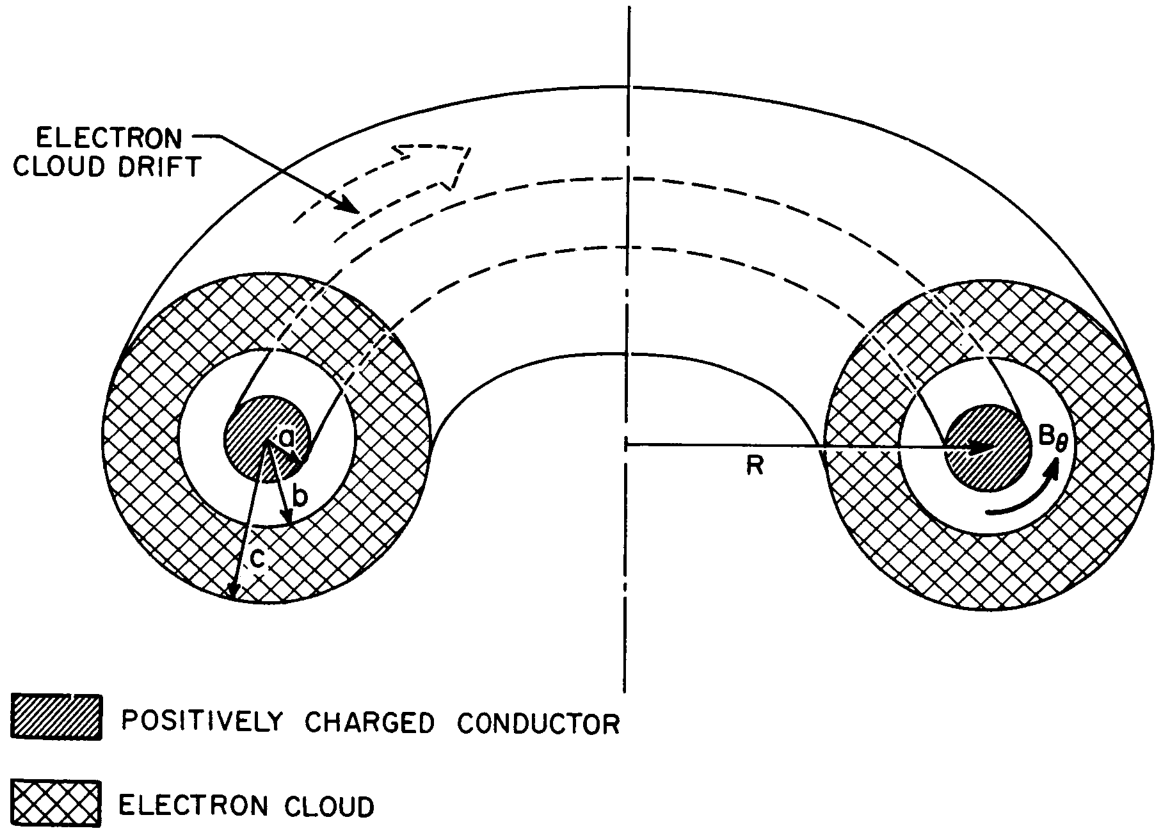

Fig. 3 An idealized version of the Plasma Radiation Shield used for study of the diocotron effect. The electron cloud is confined within two concentric toroidal surfaces having minor radii b and c.

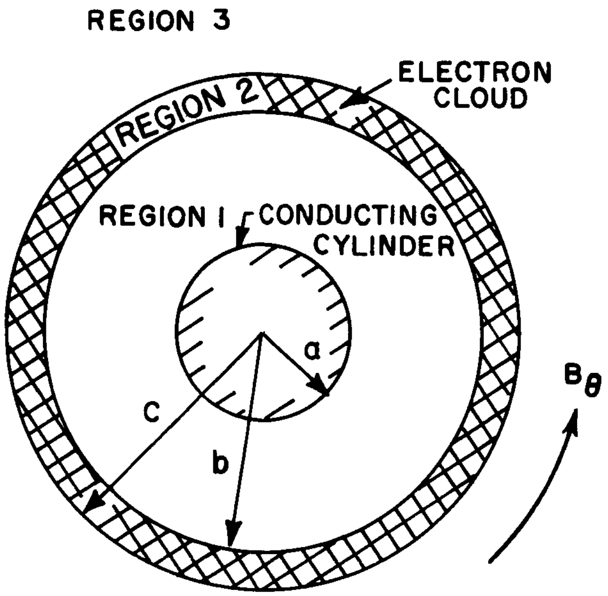

Fig. 4 An approximation to the geometry of Fig. 3 used in the study of the diocotron effect.

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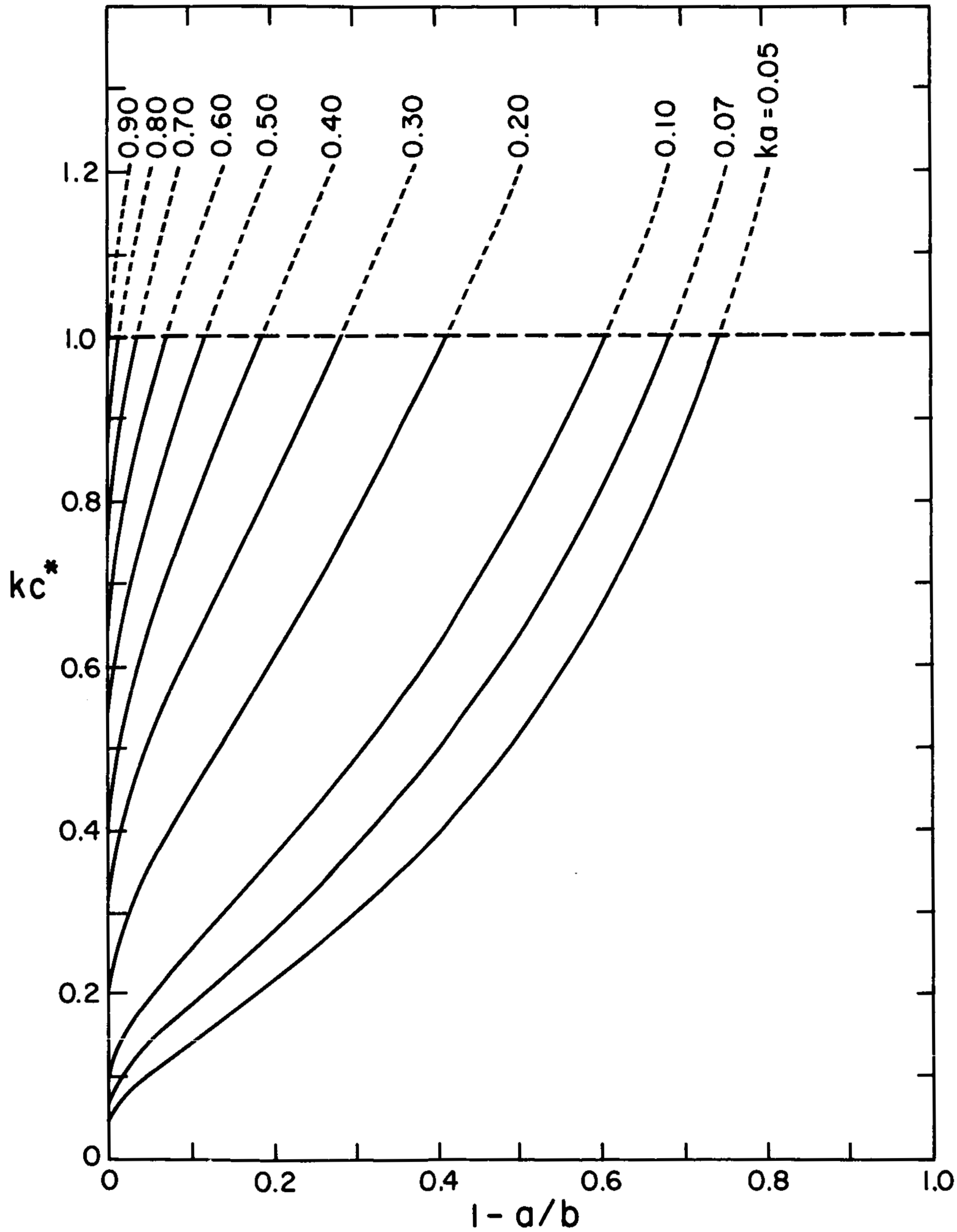

Fig. 5 The stability plot for the geometry of Fig. 3. If b is close enough to a, or if the cloud is thick enough, stability against the diocotron modes considered can be expected. For a detailed interpretation of this plot, see Ref. 1.

approximation to a torus with a large radius ratio, it is shown that the crossed field electron beam surrounding a space radiation shield will, within the same approximations, be stable against diocotron instabilities when the beam is sufficiently thick.

In another direction, the coherent radiation study has been extended to the interior toroidal geometry. No instability has been found and (although there is no proof as yet) none is expected. This is for the following reason: if the electron beam rotates with a certain angular frequency $\omega = v/r$, oscillations would probably be found at about the same frequency. Here v is the electron velocity and r the minor radius of the interior torus. Now the free space wavelength at the frequency ω is $\frac{rc}{v}$ and this (since $v < c$) is a length greater than r. Consequently, viewed as a waveguide, the cylinder is cut off and cannot contain any wave originating in the electron beam. Of course, if the surface of the cylinder were altered to provide a "slow wave structure" this conclusion would not hold. The argument given here is (at this stage) plausible but not proven. If true, it has an interesting consequence: it will be very difficult to verify the existence of the radiating instability experimentally, if the experiment is performed in a conducting (stainless steel, for instance) vacuum tank. Reflection of the radiation from the wall will seriously interfere with the growth of the instability. It may be desirable to attempt an experiment in space to verify the existence and study the control of this instability. Naturally, these ideas are still somewhat provisional.

As far as work on the ω_p^2/ω_c^2 instability is concerned, the results outlined in the previous quarterly appear to have been substantiated. A paper on this subject is now in preparation, and should be completed during the next quarter. A provisional abstract of this paper follows:

"The Stability of Crossed-Field Electron Beams"

O. Buneman, R. H. Levy, L. M. Linson

ABSTRACT

The stability of crossed-field electron beams is treated for arbitrary values of the parameter $p = \omega_p^2/\omega_c^2$ = (plasma frequency/cyclotron frequency)^2. The theory bridges a gap between existing theories applicable for $p \ll 1$ and for $p = 1$. For wavelengths larger than the beam thickness, the instability present is related to the Kelvin-Helmholtz, diocotron or slipping stream instabilities, and is not importantly affected by the value of p. For short wavelengths (p-times shorter than the beam thickness) the growth rates decline roughly as $e^{-p^{-1}}$ and become unimportant for $p \lesssim .05$. These results are useful in explaining a number of experimental observations relating to Penning-type discharges.

IV. PUBLICATIONS

The following papers have been prepared so far under the NASA program:

1. Levy, R.H., "The Diocotron Instability in a Cylindrical Geometry," Avco-Everett Research Laboratory Research Report 202, Phys. of Fluids, Vol. 8, July 1965, p. 1288.

2. Levy, R.H., "The effect of Coherent Radiation on the Stability of a Crossed-Field Electron Beam," Avco-Everett Research Laboratory Research Report 213, June 1965. To be published J. Applied Phys.

3. Levy, R.H. and Janes, G.S., "The Electron Plasma-Experiment, Theory and Applications," Avco-Everett Research Laboratory AMP 160, June 1965. AIAA Paper No. 65-538.

4. Janes, G.S., Levy, R.H. and Petschek, H.E., "The Production of BeV Potential Wells," Avco-Everett Research Laboratory AMP 166, Phys. Rev. Letters, Vol. 15, No. 4, 138, 26 July 1965.

5. Levy, R.H. and Callen, J.D., "The Diocotron Instability in a Quasi-Toroidal Geometry," Avco-Everett Research Laboratory Research Report 228, August 1965. To be published in Physics of Fluids.

Items 1, 3 and 4 have already been published in the open literature. Items 2 and 5 will also be published in due course. A further paper is in preparation dealing with the ω_p^2/ω_c^2 stability problem.

V. CONCLUSIONS

Good progress continues to be made in all phases of the Plasma Radiation Shielding work. The outline of work to be undertaken in the near future includes:

a) Experimental

Injection using the induced electric field, and the construction of a toroidal (lab geometry) experiment will both be pursued.

b) Theoretical

A good grasp of the major likely sources of instability has been obtained. It is important to correlate existing studies with experimental results, and to seek in the latter suggestions for further theoretical work. It seems probable that the "cold plasma" approximation has been pushed as far as it can; it is not yet clear whether (or to what extent) it will be necessary to study "warm plasma" effects. The entire magnetron industry appears to have worked successfully (if somewhat empirically) without, until very recently at least, bothering about warm plasma effects.

c) Practical

Until some really high voltages have been produced in a toroidal geometry in the lab, it does not seem worthwhile to refine still further the weight estimates of Plasma Radiation Shields already made. It is hoped, however, that serious consideration will be given to a possible experiment in space to test the basic principles and operation of a small-scale Plasma Radiation Shield. Reasons for thinking in terms of a space experiment are: (1) Support difficulties in the lab, and (2) The question of the radiating instability being suppressed by the walls of the vacuum vessel. Of course, alternative experiments on the ground will also be considered.

REFERENCES

1. Levy, R.H. and Callen, J.D., "The Diocotron Instability in a Quasi-Toroidal Geometry," Avco-Everett Research Laboratory Research Report 228, August 1965. To be published in Physics of Fluids.